



## СЕЙСМОСТОЙКОСТЬ СООРУЖЕНИЙ SEISMIC RESISTANCE

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### The effect of story drift in a multi-story building under the influence of an earthquake

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**Abstract.** This paper content is structure subjected sudden story drift as a result from earthquakes, forming hinges and eventually collapsing. The aim of this paper is to develop building thirty story building for seismic in Khartoum using finite element method (FEM) and the equivalent lateral force (ELF) procedure of American code ASCE 7-16. In current work the thirty-story reinforced concrete building was considered is to analyze the seismic behavior of the reinforced concrete structure to find the drift between the story by finding the maximum displacement from the program that causes the building to collapse, by choosing the shear wall as the support system to resist the lateral load and by looking to model the building inclined to the horizontal plane. Calculations were also made on the drift between the story to compare with the allowable drift. It is implemented in the Robot structural program – an ingenious program for designing and analyzing lateral (seismic) loads.

**Keywords:** story drift, reinforced concrete, building, displacement, seismic behavior

### Влияние смещения этажей в многоэтажном здании под воздействием землетрясения

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**Аннотация.** Изучается структура здания, подвергнутого в результате землетрясений внезапному смещению этажей, образующему петли и приводящему к разрушению строения. Цель исследования – разработать тридцатэтажное сейсмическое здание в Хартуме с использованием метода ко-

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нечных элементов (МКЭ) и процедуры эквивалентной боковой силы (ELF) американского кодекса ASCE 7-16. Анализируется сейсмическое поведение железобетонной конструкции тридцатиэтажного железобетонного здания для определения смещения между этажами путем нахождения максимального смещения по программе, приводящего к разрушению здания, выбора сдвиговой стены в качестве опорной системы для сопротивления боковой нагрузке и моделирования здания, наклоненного к горизонтальной плоскости. Расчеты по смещению между этажами для определения допустимого смещения проведены в структурной программе Robot (оригинальная программа для проектирования и анализа боковых (сейсмических) нагрузок).

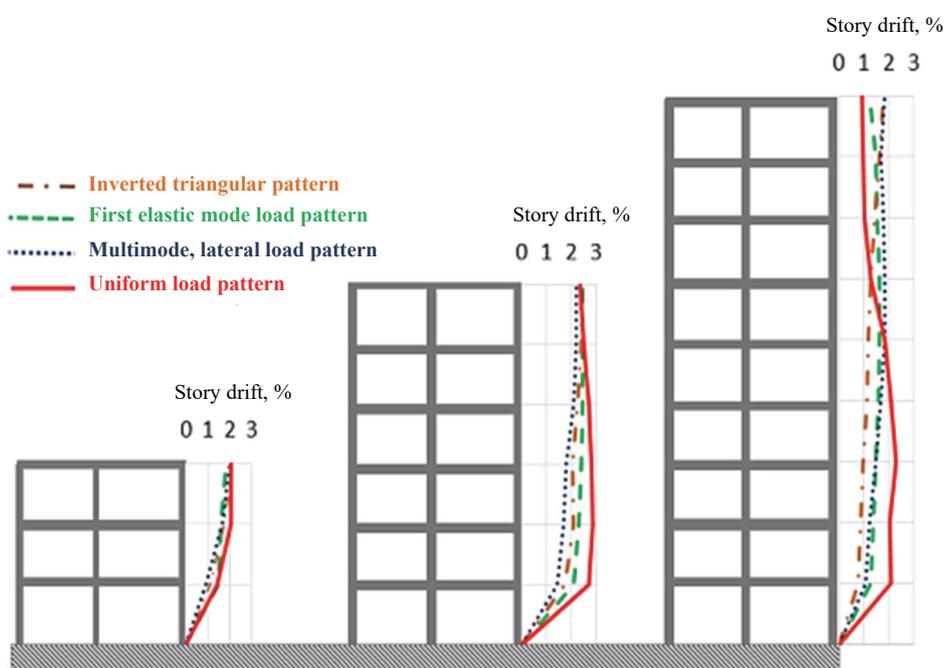
**Ключевые слова:** смещение этажей, железобетон, здание, смещение, сейсмичность

**Introduction**

Multi-story structures made of reinforced concrete hold a significant market share in the world. The position of the shear wall should be carefully considered as it gives different seismic load resistance performance [1]. These structures are typically upheld laterally by cantilever shear wall or foundation wall, which are discarded asymmetrically around the structure causing a large displacement of the stiffness center (CR) from the mass center (CM) of the structure. The displacement, also known as the central eccentricity, can amplify a large building displacement in seismic conditions, thus increasing the building's exposure to severe damage [2]. The displacement request of a building is always more important at its edges.

Drift has been defined in terms of total drift (the total lateral displacement at the top of the building) and inter story drift is defined as the relative lateral displacement occurring between two consecutive building levels. The drift index is a simple estimate of the lateral stiffness of the building and is used almost exclusively to limit damage to nonstructural components [3].

Lateral deflection and drift affect the entire building or structure [4]. Above 25 stories, the relatively high lateral flexibility of the frame calls for uneconomically large members in order to control the drift [5].



**Figure 1.** The story drift profile along the height of frames [6]

In Figure 1, story drift profiles are introduced along tire heights dependent on the invert three-sided load designs, flexibility first mode, multi-mode, and uniform examples. Likewise, nonlinear sequential history analyzes were performed on case study framework for specific ground movements.

## System structure used to reduce the displacement due to the earthquake framed tube structures

In this system, the perimeter of the building consists of closely spaced columns connected by deep spandrel beams (Figure 2) [2]. The system works quite efficiently as a hollow vertical cantilever. However, lateral drift due to the axial displacement of the columns commonly referred to as chord drift and web drift, caused by shear and bending deformations of the spandrels and columns, may be quite large depending upon the tube geometry. For example, if the plan aspect ratio is large, say, much in excess of 1:2.5, it is likely that supplemental lateral bracing may be necessary to satisfy drift limitations. The economy of the tube system therefore depends on factors such as spacing and size of columns, depth of perimeter spandrels, and the plan aspect ratio of the building.

This system should, however, be given serious consideration for buildings taller than about 40 stories. In its simplest terms, a framed tube can be defined as a three-dimensional system that engages the entire building perimeter to resist lateral loads. To create a wall-like three-dimensional structure it is a necessary requirement to place columns on the building exterior relatively close to each other, joined by deep spandrel girders.

## Shear wall

Shear walls are reinforced concrete walls that are used in tall buildings to resist loads from wind or seismic movements in addition to vertical loads. Shear wall is one of the most commonly used lateral load resisting systems in buildings. Shear wall has high plane stiffness and strength which can be simultaneously resist large horizontal loads and support gravity loads, which significantly reduces the lateral sway of the building and there by reduces damage to structures and its contents.

When the shear wall is strong enough, it will transfer the horizontal load to the next element in the load path below them such as floors, other shear walls, slabs or footings. Shear wall also provides lateral stiffness to prevent the roof or floor above from large lateral sway. When shear wall is stiff enough, they will prevent floor and roof from moving off their supports. Also, buildings that are sufficiently stiff will usually suffer less non-structural damage.

Shear walls behavior depends upon the material used, wall thickness, wall length, wall positioning in building frame. Since shear wall carry large horizontal earthquake forces, the overturning effects on it is large. Shear wall in buildings must be symmetrically located in plan to reduce ill-effects of twist in buildings. When shear wall is placed in advantageous positions in the building, they can form an efficient lateral force resisting system by reducing lateral displacements under earthquake loads [7]. Shear walls carry the adequate lateral strength to resist incoming horizontal earthquake forces [8].

The shape and plan position of the shear wall influences the behavior of the structure considerably, the position of shear wall will affect the attraction of forces, so that wall must be in proper position. If the dimensions of shear wall are large then major number of horizontal forces are taken by shear wall. Providing shear walls at adequate locations substantially reduces the displacements due to earthquake [9]. The design base shear ( $V_b$ ) shall be distributed along the height of the building as per the [10].

The walls are in various forms such as U, I, T, L, E, or as a line and are usually continuous until the bases are in a cantilever shape. These mentioned walls may be solid or container on the openings, depending on the architectural function performed by the wall, but it is worth noting that the openings increase the complexity of the construction work, especially in those cases where these openings are asymmetrical, infrequent, or irregular. Although shear walls are often suitable in concrete structures, we find that they are sometimes used as part of steel structures containing huge steel panels, especially in areas exposed to maximum values of shear forces. The walls are single, or (Link Wall), which connects to the slabs or beams while neglecting the moments, or (Coupled Wall), which is connected by elements to resist moment.

A Ravi Kumar et al [11] conducted a thorough study for determining the solution for shear wall location in multi-story building as shown as in Figure 2 based on its elastic and plastic behaviors. He analyzed a 10-storey building, 40 m in height for earthquake load using ETABS. He concluded that shear walls are one of the most effective building elements in resisting lateral forces during earthquake and for a developing nation shear wall construction is considered to be a back bone for construction industry [11].

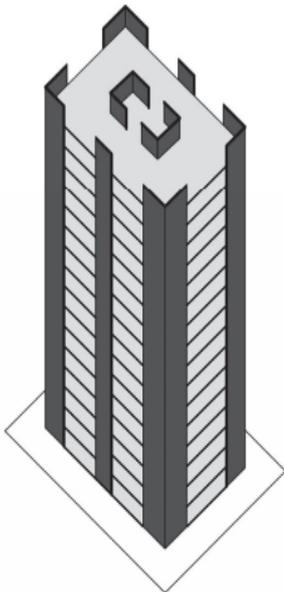


Figure 2. Shear wall system [12]

### Coupled shear walls system

In many shear wall buildings, a regular pattern of openings will be required to accommodate windows, doors, or both, shear walls such as those shown in Figure 3 [13], exhibits a stiffness that far exceeds the summation of the individual wall stiffnesses. This is because the interconnecting slab or beam restrains the cantilever bending of individual walls by forcing the system to work as a composite unit. It is seen that the total overturning moment,  $M$ , in the wall without openings shown in Figure 4, *a*, is resisted at the base entirely by flexural stresses. On the other hand, shown in Figure 4, *b, c*, axial forces as well as moments occur at the base to resist the overturning moment. This system is economical for buildings in the 40-story range. Since planar shear walls carry loads only in their plane, walls in two orthogonal directions are generally required to resist lateral effects.

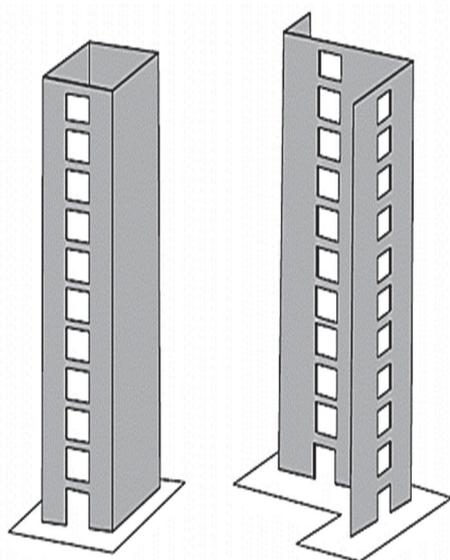


Figure 3. Coupled shear walls [13]

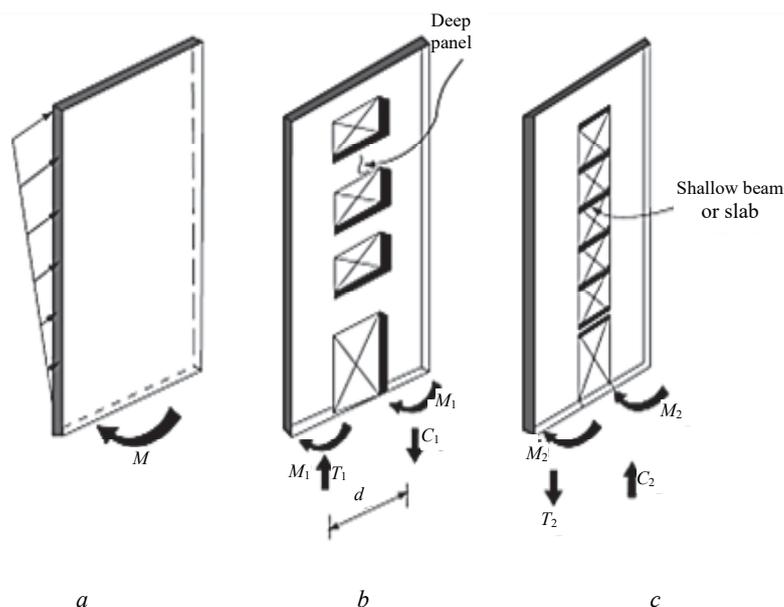


Figure 4. Lateral load-resistance of single and coupled shear walls [13]

Position of shear wall need to be considered carefully because it gives difference performance to resisting earthquake load. In choosing suitable locations for lateral-force-resisting shear walls, three additional aspects should be considered:

1) for the best torsional resistance, as many of the walls as possible should be located at the periphery of the building;

2) in multi-story buildings situated in high-seismic-risk areas, a concentration of the total lateral force resistance in only one or two shear walls are likely to introduce very large forces to the foundation structure, so that special enlarged foundation may be required;

3) the more gravity load can be routed to the foundations via a shear wall, the less will be the demand for flexural reinforcement in that wall and the more readily can foundations be provided to absorb the overturning moments generated in that wall [14].

Ideally, the structural engineer should select the most suitable structural elements to resist gravity and lateral (wind and seismic loads). However, perfect design conditions are seldom present. A structural engineer must understand the following limitations to the most efficient design:

- interior planning for architects;
- selected materials;
- architects' selection of exterior cladding and décor;
- the size of the expected horizontal loads;
- height determined by the owner and architectural preferences.

The walls are single, or link wall, which connects to the slabs or beams while neglecting the moments, or coupled wall, which is connected by elements to resist moment.

### Methodology

In order to calculate the drift, we created a thirty-story model in the Robot structural program and made an analysis according to the ASCE 7-16 code<sup>1</sup>. The results of this analysis will help to obtain the maximum displacement. To find the drift, we did calculations in Excel sheet.

To determine the design of story drift, as shown in Table 12.12-1 in code ASCE 7-16, involves the following steps:

1. Determine the lateral deflections at the different floor levels by an elastic investigation of the structure under the design base shear. The lateral deflection at floor level  $x$ , gotten from this analysis, is  $\delta_{max}$ .

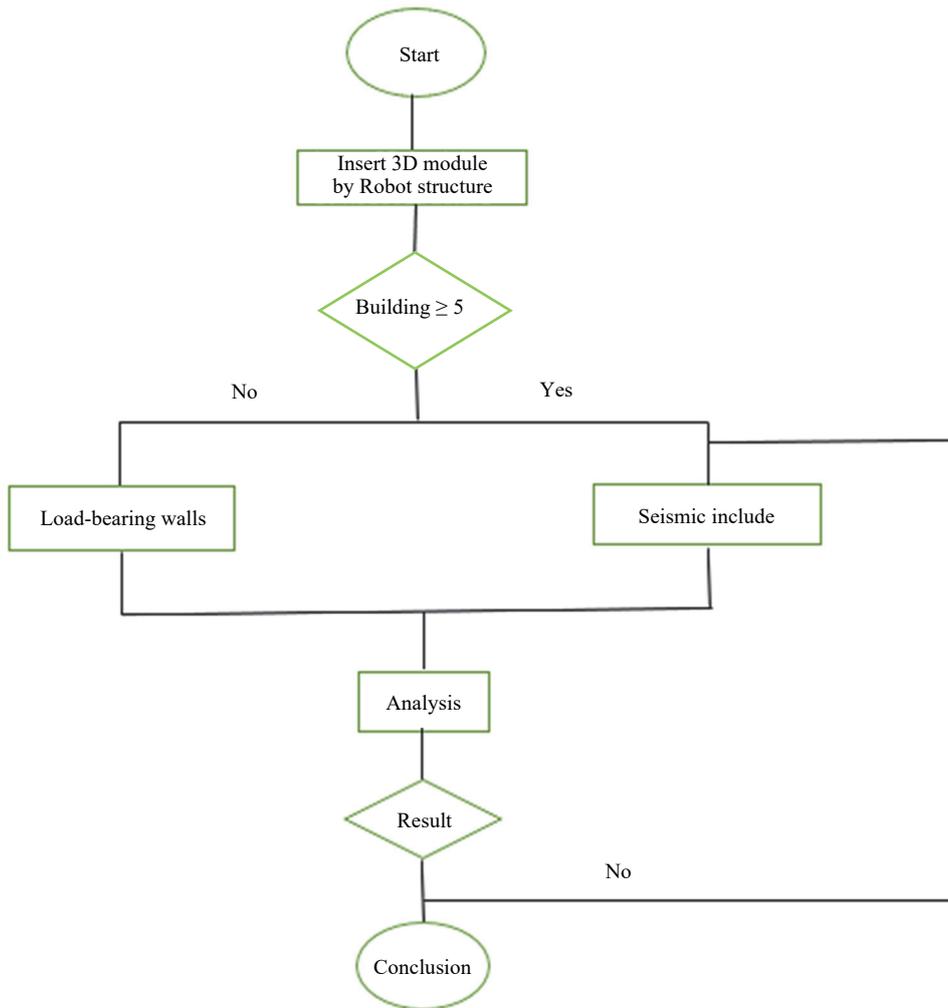


Figure 5. Algorithm process for project

2. Amplify  $\delta_{xe}$  by the deflection amplification factor,  $C_d$ . The amount  $C_d\delta_{max}$  is an expected design seismic displacement at floor level  $x$ . ASCE 7–16 requires this amount to be isolated by the importance factor,  $I_e$ , because the forces under which the  $\delta_{max}$ , displacement is registered are already amplified by  $I_e$ . Since ASCE 7-16 drift limits are tighter for structures in higher inhabitation classes, this division by  $I_e$  is significant. Without it, there would be a twofold fixing of drift impediments for structures with seismic significance factors more prominent than one.

$$\delta_m = \frac{\delta_{max} \cdot C_d}{I_e} \tag{1}$$

<sup>1</sup> ASCE/SEI 7-16. Minimum design loads and associated criteria for buildings and other structures. American Society of Civil Engineers; 2017.

Calculation earthquake eccentricity direction Y, for stories parking and center 1:  $\delta_{\max}^{\text{Center}} = 1.5$ ;  $\delta_{\max}^{\text{Parking}} = 0.3$ ;  $C_d = 4.5$ .

$$\delta_m(\text{parking}) = \frac{4.5 \times 0.3}{1} = 1.35 \text{ mm.}$$

$$\Delta_s(\text{parking}) = \delta_m(\text{parking}) - 0 = 1.35 - 0 = 1.35 \text{ mm.}$$

$$\delta_m(\text{Center 1}) = \frac{4.5 \times 1.5}{1} = 6.75 \text{ mm.}$$

$$\Delta_s(\text{Center 1}) = \delta_m(\text{Center 1}) - \delta_m(\text{Parking}) = 6.75 - 1.35 = 5.4 \text{ mm.}$$

The quantity  $C_d \delta_{xe} / I_e$  at floor level  $x$  is  $dx$ , the adjusted design earthquake displacement.

3. Calculate the design story drift  $\Delta_x$  for story  $x$  (the story underneath floor level  $x$ ) by deducting the changed design seismic displacement at the lower part of story  $x$  (floor level  $x-1$ ) from the changed design seismic displacement at the highest point of story  $x$   $\Delta_x = \delta_x - \delta_{x-1}$ .

The  $\Delta_x$  values must be kept within limits, as given in ASCE 7-16 code for (Table 12.12-1).

Let us consider a fragment of the algorithm Figure 5 for creating a digital of a structure, namely, the process from the beginning of drawing 3D modeling to the result of the story drift check.

During the study, a drawing of 30 floors will be used by the structural robot program. The building will be analyzed after loading the loads for each floor by using the ASCE 7-16 code. This will be followed by the third stage: the structural model will be done by making the calculations and comparing them manually. In the next (fourth) stage, we determine if the results are identical and meet the requirements of the analytical investigations of the building, and after that, the design determines whether the resulting model meets the requirements for completion.

### Result and discussion

The drift evaluation was checked as demonstrated in Table, to calculate the displacement, by taking data from program. Equivalent linear static analysis of the case study structures was performed using a primary Robot dependent on lateral force. Identified as ASCE 7-16 code for seismic work in Sudan. The seismic mass was determined considering 100% of the dead load and 25% of the storage load, the horizontal surface forces were resolved dependent on the seismic load. After determining the lateral forces, static linear analyzes were performed on each of the thirty story buildings. The static analysis procedure is used to obtain the maximum displacement. From the formula (1) we should find the amplified displacement. By deduct between the two amplified displacement stories we should find the story drift.

#### Calculation check drift from Excel

EQECC DIRECTION Y						
$C_d = 4.5$		$I_e = 1$		$D_m = 0.02$		
Story	High	Maximum elastic displacement	Amplified displacement	Story drift	Allowable drift	Check
		$\delta_{\max}$	$\delta_m$	$\Delta_s$	$\Delta_a$	
Parking	2800	0.3	1.35	1.35	56	Ok
Center 1	2800	1.5	6.75	5.4	56	Ok
Center 2	3500	4.5	20.25	13.5	70	Ok
Center 3	3500	9.3	41.85	21.6	70	Ok
Center 4	3500	15.5	69.75	27.9	70	Ok

The end of the Table

EQECC DIRECTION Y						
$C_d = 4.5$		$I_e = 1$		$D_m = 0.02$		
Story	High	Maximum elastic displacement	Amplified displacement	Story drift	Allowable drift	Check
		$\delta_{max}$	$\delta_m$	$\Delta_s$	$\Delta_a$	
Center 5	3500	22.9	103.05	33.3	70	Ok
Story 1	3000	30.1	135.45	32.4	60	Ok
Story 2	3000	37.9	170.55	35.1	60	Ok
Story 3	3000	46.4	208.8	38.25	60	Ok
Story 4	3000	55.3	248.85	40.05	60	Ok
Story 5	3000	64.6	290.7	41.85	60	Ok
Story 6	3000	74.3	334.35	43.65	60	Ok
Story 7	3000	84.3	379.35	45	60	Ok
Story 8	3000	94.5	425.25	45.9	60	Ok
Story 9	3000	104.9	472.05	46.8	60	Ok
Story 10	3000	115.5	519.75	47.7	60	Ok
Story 11	3000	126.2	567.9	48.15	60	Ok
Story 12	3000	136.9	616.05	48.15	60	Ok
Story 13	3000	147.6	664.2	48.15	60	Ok
Story 14	3000	158.3	712.35	48.15	60	Ok
Story 15	3000	168.9	760.05	47.7	60	Ok
Story 16	3000	179.5	807.75	47.7	60	Ok
Story 17	3000	189.9	854.55	46.8	60	Ok
Story 18	3000	200.3	901.35	46.8	60	Ok
Story 19	3000	210.5	947.25	45.9	60	Ok
Story 20	3000	220.6	992.7	45.45	60	Ok
Story 21	3000	230.6	1037.7	45	60	Ok
Story 22	3000	240.4	1081.8	44.1	60	Ok
Hall	3000	250.5	1127.25	45.45	60	Ok
Roof	4000	263	1183.5	56.25	80	Ok

## Conclusion

This paper explains the contents of the drift between stories, and the use of some theories to reduce the drift. After analyzing the structural model from the Robot structural analysis, we used the maximum displacement of the story in the  $Y$  direction. It's evident from Table that for all stories the lateral drift obtained from the prescribed lateral force in direction  $Y$  are less than the limiting value.

The allowable overall building drift for strength level Earthquake was  $\Delta_s < 0.020hs_x$  from ASCE 7-16. The allowable overall building drift for strength level earthquake is  $H/50 = 92\,600 / 50 = 1852$  mm and the building drift is 1183.5 mm which is within the limit. Thusly, it is protected to utilize the shear wall in the model. Based on this study, it was seen that the utilization of shear wall can contribute to increased structural rigidity. It diminishes the regular time of structure, lateral displacement and story-drift essentially.

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